Grand Challenge Research on BioSensors – Avoiding Information Overload

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There are countless aspects of biological systems that intrigue and inspire engineers and scientists. As an Aerospace Engineer, historical connections to bioactuation form the foundation of our field. Mimicry of the heavier-than-air, flight capabilities of biological systems date to ancient Greek myths and tales of Icarus and to Leonardo DaVinci's famous 15th century sketches of ornithopters. The Wright brothers and many of their peers literally credit years of studying avian models (bird-watching) for providing key insights and the essential understanding of flight control systems inherent in the designs that lead to their first successful manned flights. Within the past century, both evolutionary and revolutionary technology advances have enabled flight capabilities seen in jumbo jets, the space shuttle and hypersonic X-planes, systems that perform missions far removed from those of their predecessors. Yet, biological models continue to inspire creative new directions for aeronautical research, as demonstrated by major NASA and DARPA investments in morphing vehicle technologies and in (low Reynolds number) micro-air vehicles. We have over a century of experience in drawing inspiration from the macroscale behaviors of biological systems. With good reason, though, we remain in awe of the integrated sensing, decision-making, control and actuation capabilities of biological models.

Advanced MEMs and NEMs sensor systems offer means for increasing sensor density, and the quantity and quality of sensed information. However as implemented, they often provide only incremental performance gains associated with miniaturization of sensors and over-sampling of information needed only intermittently, and introduce the associated challenges of acquiring, digitizing, assimilating and storing many more channels of sensed information than previously possible. Somewhere short of creating a brain, and/or embedding artificial intelligence or cognition in inanimate objects, lie enormous opportunities for: *1) developing and validating models of the biological and biochemical processes with which biological systems efficiently manage large quantities of time-varying and spatially-distributed sensory information and 2) transitioning these processes to engineered (man-made) systems***.**

Over the past decade, the proliferation of here-to-fore unavailable instruments for studying biological, bioelectrical and biochemical processes in-vitro, in-vivo, and at the nanoscale offer unique capabilities needed for moving beyond miniaturization of macroscale sensor and actuator concepts. This will lead to revolutionary insights for implementing integrated nanotechnology-based components made possible through comprehension of biosensor and bioactuator processes. Returning to avian models, birds are continually processing information about their flight environment and coordinating their wing, body, tail feathers, feet and head positions to achieve immediate flight performance objectives in response to gusts and/or moving targets (Fig. 1). The primary gust detection mechanism in birds is associated with the ability to sense wind direction as gusts ruffling the feathers stimulate distributed sensory receptors located in the skin around the base of their feathers. At a macroscopic scale, this might reduce to a feed-forward control loop process in which vision is the input sensor guiding and updating the brain/controller commands to wing muscles as needed to achieve maneuvering objectives. Yet little is understood of the biochemical and bioelectrical responses to sensing the distributed gust responses or visual cues of moving prey and subsequent processing of the significant quantities of time and spatially varying data that would at other times be irrelevant to the flight objective and ignored. Fascinating opportunities exist for drawing upon new insights into biosensors for changing how we design sensor arrays, choose the information to collect and prioritize processing of sensed information.

Fig.1 Hummingbird (Wayne Owens, Humabout.net) and lark (Alan Moss, the Hawk Conservancy Trust).